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NINTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

From Today's Tools and Practices to Tomorrow's Investments: New Directions in Systems Engineering

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14. ABSTRACT
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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the ARP:

- Office of the Under Secretary of Defense (Acquisition, Technology, & Logistics)
- Director, Acquisition Career Management, ASN (RD&A)
- Program Executive Officer, SHIPS
- Commander, Naval Sea Systems Command
- Program Executive Officer, Integrated Warfare Systems
- Army Contracting Command, U.S. Army Materiel Command

- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
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- Director of Open Architecture, DASN (RDT&E)
- Program Executive Officer, Littoral Combat Ships

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this symposium.

James B. Greene Jr.	Keith F. Snider, PhD
Rear Admiral, U.S. Navy (Ret.)	Associate Professor

Panel 14. Front-End System Engineering

Thursday, May 17, 2012	
9:30 a.m. – 11:00 p.m.	**Chair: Dr. Michael McGrath,** Vice President, Systems and Operations Analysis, Analytic Services Inc. ***The Macro Dynamics of Weapon System Acquisition: Shaping Early Decisions to Get Good Outcomes*** Edward Kraft, *Arnold Engineering Development Center* ***An Experience Accelerator for the Engineering Workforce*** Jon Wade, *Stevens Institute of Technology* ***From Today's Tools and Practices to Tomorrow's Investments: New Directions in Systems Engineering*** Robert Neches, *Office of the Deputy Assistant Secretary of Defense for Systems Engineering* James Carlini, *James Carlini Consulting* Robert Graybill, *Nimbis Services Inc.* Robert Hummel, *Potomac Institute for Policy Studies* Michael McGrath, *Analytic Services Inc.*

Michael McGrath—Dr. McGrath is the vice president of Systems and Operations Analysis (SOA), Analytic Services, Inc. He became the vice president in October 2007. He leads ANSER's operations in the Science and Technology, Enterprise Systems and Planning, and Operations Analysis and Management mission areas. He is responsible for developing and delivering services that enable the clients of Analytical Services Inc. to address critical challenges in national security and public safety, and to improve the effectiveness of public-sector programs. Dr. McGrath leads a workforce whose expertise spans a wide range of technology and application domains in research, acquisition, information systems and defense operations.

Dr. McGrath served as Deputy Assistant Secretary of the Navy for Research, Development, Test, and Evaluation from February 2003 to September 2007. His role was to aggressively drive new technologies from all sources across Navy and Marine Corps platforms and systems and to develop programs to bridge the gap in transitioning from science and technology to acquisition. He was also responsible for integrating test and evaluation with the evolutionary acquisition process. His leadership was key to the restructuring of the Future Naval Capabilities program, the success of the Rapid Technology Transition program, and the establishment of the Navy Enterprise T&E Board of Directors and the Navy Lab and Centers Competency Group.

Prior to his return to government service in 2003, Dr. McGrath spent five years as vice president for Government Business at the Sarnoff Corporation, a leading R&D company with both commercial and government clients. He was responsible for developing programs to meet government needs for innovative dual use technologies in sensors and microelectronics, networking and information technology, and bio-technology.

Dr. McGrath's previous government experience includes weapon system logistics planning and management at Naval Air Systems Command, acquisition policy in the Office of the Secretary of Defense, and several technology management positions. He was the first OSD director of the Computer-Aided Acquisition and Logistics Support program. At DARPA, he managed programs in Agile Manufacturing, Electronic Commerce Resource Centers, and Affordable Multi Missile Manufacturing. He also served in leadership positions for several DoD-wide initiatives to improve manufacturing and reduce the cost of defense systems. As the Assistant Deputy Under Secretary of Defense (Dual Use and Commercial Programs), he directed the Commercial Technology Insertion Program, the Commercial Operating and Support Savings Initiative, and the Department's Title III industrial base investments.

Dr. McGrath holds a BS in space science and applied physics (1970) and an MS in aerospace engineering (1972) from Catholic University, and a doctorate in operations research from George Washington University (1985). He was an adjunct associate professor at GWU in 1987–1988. He is active in several industry associations and study groups, including studies by the Defense Science Board and the National Research Council.

From Today's Tools and Practices to Tomorrow's Investments: New Directions in Systems Engineering

Robert Neches—Dr. Neches is the director for Advanced Engineering Initiatives in the Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD[SE]). He is responsible for fostering technology development enabling innovation in design and system engineering practices across the Department of Defense (DoD) and its industrial suppliers of new products, systems, and technologies. Dr. Neches serves as the Priority Steering Council lead for Engineered Resilient Systems (ERS). ERS is one of the seven DoD-wide science and technology topic areas that have been designated as a crosscutting priority for the next five years by the Secretary of Defense. He has previously served as a program manager at DARPA with responsibilities for human–computer interaction, information integration, and planning and decision aids. As a member of the research faculty of the University of Southern California Computer Science Department, he has nearly 100 publications. [Robert.Neches@osd.mil]

James Carlini—Mr. Carlini is the founder of James Carlini Consulting, a specialized defense and space services organization in the Washington, DC, metro area. He is currently a member of the United States Air Force Scientific Advisory Board and has previously served on the United States Army Science Board. He has served as the vice president of Advanced Development Programs at Northrop Grumman Corporation, director of the Special Projects Office at DARPA, and as a senior engineer at Science Applications International Corporation. [jimcarlini@msn.com]

Robert Graybill—Mr. Graybill, president and CEO of Nimbis Services Inc., has more than 35 years of HPC related senior-level experience as a business leader, government program manager, and technology researcher. In addition to leading Nimbis, Mr. Graybill is engaged in a number of high visibility HPC competitiveness projects, application portal initiatives, cloud standardization efforts, and digital manufacturing model based engineering consulting projects with the DoD and industry. During his six years at DARPA, he spearheaded six new transformational programs and received the Secretary of Defense Medal for Outstanding Public Service. He has participated in numerous government studies, including the Defense Science Board Task Force on DoD Supercomputing Needs and the High-End Computing Revitalization Task Force, and currently serves on the Air Force Science Advisory Board. [robert.graybill@nimbisservices.com]

Robert Hummel—Dr. Hummel is vice president for research at the Potomac Institute for Policy Studies, a think tank located in the Washington, DC, area, focusing on science and technology for business and government and the implications for policy-makers. Previously, he was a principal at Booz Allen Hamilton, responsible for the science and technology services and innovation strategies for government and industry. Dr. Hummel was a program manager at DARPA, where he received the Director's Award for Personal Achievement, serving in the Offices for Information Systems, Special Projects, and Information Exploitation. Prior to joining DARPA, he was a tenured professor at the Courant Institute of Mathematical Sciences at New York University with over 70 published journal and refereed conference articles. [rhummel@PotomacInstitute.org]

Michael McGrath—Dr. McGrath is vice president for systems and operations analysis at Analytic Services Inc. (ANSER), a not-for-profit government services organization. He previously served as the Deputy Assistant Secretary of the Navy for Research, Development, Test, and Evaluation, where he was a strong proponent for improvements in technology transition, modeling and simulation, and test and evaluation. In prior positions, Dr. McGrath served as vice president for government business at the Sarnoff Corporation, assistant director for manufacturing at the Defense Systems Research Projects Agency (DARPA), and director of the DoD Computer-aided Acquisition and Logistics Support (CALS) program. He has maintained research interests in information systems, systems engineering, and manufacturing technologies. He is a member of the National Research Council Board on Materials and Manufacturing. [Michael.mcgrath@anser.org]

Abstract

This presentation discusses challenges to the rapid execution of acquisition programs that would introduce affordable, effective, and adaptable systems into widespread use in a timely fashion. It suggests a revamping of the engineering process that would address these challenges, and describes the technical enablers that make that revamping feasible.

Executive Summary

We must do no less than to transform the engineering of complex systems to make them affordable, effective, and adaptable. Doing so will enable engineers and program decision-makers to collaboratively focus on building the right things to provide utility in a wide range of joint operations, and across many potential alternative futures.

Increased computational power and availability allow us to exploit data and apply services in much more flexible ways. This creates an opportunity to consider capabilities and mission utility more deeply, rather than getting locked into requirements and key performance parameters. That is a critical enabler to engineering for adaptability and maximizing value of the system to the warfighter.

We believe it is time to demonstrate a new engineering ecosystem that combines automated tools and stakeholder participation to generate more counters to potential surprise.

Among the key contributing technology concepts are the following:

- co-evolution of systems and missions via information sharing and decision aids,
- option-preserving tradespace exploration,
- analyzed/evaluated with respect to lifecycle issues,
- informing requirements refinement, and
- accelerated design and testing via rapidly composable modeling & analysis tools and risk-sensitive engineering planning aids.

Introduction

The Department of Defense Strategic Plan (2012) identifies 10 strategic missions, while recognizing that the country's economic condition does not permit the luxury of addressing these needs through increased spending—or even continuation of current spending levels. It proposes seven strategic principles to ensure success, including the following:

- offer versatility,
- enable course changes,
- reduce costs, and
- develop new capabilities leveraging network warfare.

The challenge is how to build new systems, and upgrade and extend existing systems, to support these needs in a highly turbulent and unpredictable global environment.

This increases an already severe and longstanding source of stress on engineering complex systems solutions. We know that acquisition programs falter and fail, and that research, development, testing, and evaluation expenses consume resources better spent on buying more units of the product under development. Careful upfront engineering is required, with allowances for insertion of new technology and mitigation of risk if the technologies do not arrive on schedule. Unfortunately, we do not have the resources to do it right today—much less in the rapidly coming future environment.

The conventionally touted solutions to this problem are not viable.

Dr. Edward Kraft, presenting in this panel, has shown that programs have much stronger likelihoods of success if restricted to “tried and true” technologies (i.e., technology readiness level 6 or above). However, in the future, we cannot restrict technology in this fashion. In a world of increasing global capability, to do so would cede technological superiority in weapons systems.

Although today’s processes are provably effective when followed fully, it is increasingly difficult to do so. The workforce is aging, and neither the personnel nor the funding nor the will are available to continue to work in that mode. Dr. Kraft has also shown that the ratio of engineering work to program cost in the DoD has risen from 10% to 20% in the 1950s and from 40% to 60% today. We cannot follow engineering process mandates today. Worse, those processes treat time and money as dependent variables that can be allowed to slip.

The pace of technology, events, and innovation by opponents make time slippage untenable. Economic realities make cost slippage untenable. We must make upfront engineering easier, faster, and more affordable.

The Problem’s Historical Roots

Today, there is a strictly sequential, non-overlapping progression in the processes we use to define what systems we will acquire.

The tasks are performed by different groups with little carryover in either membership or information. Enabling science and technology (S&T) relevant to the design process is communicated to people who are not themselves the target users, who use their best understanding of the technology as conveyed to them to map perceived needs into product visions in Analysis of Alternatives (AoA). The AoA entails a Materiel Development Decision (MDD), essentially a conclusion that something should be built (i.e., that some product is needed), followed by a Materiel Solution Analysis, which culminates in what in the defense acquisition process is known as Milestone A. This phase essentially defines what should be built and the key performance parameters that it should meet.

Milestone A is the last point at which widely varying alternatives are considered; a conceptual transition from *what* to *how* takes place, and the parties involved change.

From there, the process moves to technology development, in which prototyping (often only partial) is performed to develop confidence that the product can be built, that is, that the key performance parameters can be met. This phase leads to Milestone B, in which a successful Preliminary Design Review (PDR) is declared.

At this point, a group process has produced a conclusion that building a product is feasible, but that does not mean that a product has actually been built. Nor, if one has been built, does reaching this point mean that the way the prototype was built will scale for building that product in quantity. Those questions are addressed in the engineering and manufacturing development phase, during which questions about manufacturability, maintainability, and reliability begin to be addressed seriously.

Although a nice logical decomposition of the intellectual steps in building a system, there are a number of problems with this process. The sequentiality makes it inherently slow. Early elimination of significant alternatives prematurely eliminates options and flexibility to address issues discovered later. Turnover in personnel and association of different phases with different expertise categories leads to loss of information. Compounding this problem, decisions are made before information is available.

Studies over more than 25 years have consistently shown that 70–80% of the lifecycle cost of a complex system is determined in the early phases, but the activities (and expertise) that would impose engineering rigor on those decisions have not yet been brought to bear.

Consequently, when the process is far enough along for hidden problems with selected approaches to emerge, or new needs to be discovered, flexibility to address them has been lost. Decisions about redefining the product in the light of those discoveries are made based on engineering knowledge. However, the expertise has moved on in terms of the skill sets that could fully assess impact and opportunities regarding the effectiveness of the revised product.

This approach seems clearly wrong. Historically, however, there are good reasons why large systems engineering proceeded in the current fashion. Quite simply, doing better was not feasible in the absence of computational tools, broad access to the computational processing capabilities required to use those tools, and distributed collaboration mechanisms for bringing together the right expertise at the right time.

To be effective in this regard requires a dramatic increase in communications across engineering and acquisition activities. Such communications are vital to understand problem scope, identify interdependencies that lead to undesirable outcomes, and make informed tradeoffs and decisions.

A Proposed Solution

What we would really like to do is to make the processes of conceptual engineering, capability engineering, and production engineering much more collaborative, overlapping, and cross-fertilizing. This would bring what are now downstream knowledge and data (e.g., manufacturing and reliability engineering considerations) to bear early enough to have an impact on critical decisions. When problems are encountered later in the processes, the greater collaboration would enable retention and application of insightful knowledge about needs and recourses offered by alternative approaches.

We must do no less than to transform the engineering of complex systems to make them affordable, effective, and adaptable. Doing so will enable engineers and program decision-makers to collaboratively focus on building the right things to provide utility in a wide range of joint operations, and across many potential alternative futures.

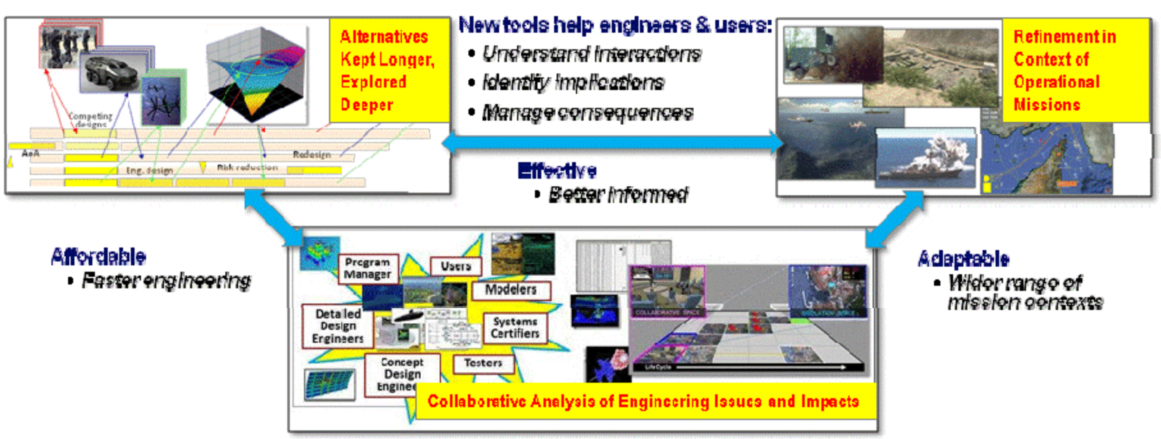

Figure 1

Increased computational power and availability allow us to exploit data and apply services in much more flexible ways. This creates an opportunity to consider capabilities and mission utility more deeply, rather than getting locked into requirements and key performance parameters. That is a critical enabler to engineering for adaptability and maximizing value of the system to the warfighter.

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Systems engineering has the challenge of addressing these problems, but if conceived as a process-oriented collection of "practices," it is simply not up to the job. For a similar conclusion, see the National Academy of Sciences (NAS) report, *Naval Engineering in the 21st Century* (NAS, 2011, pp. 89–90; Keane, 2011), which calls for tools with a particular emphasis on early design, arguing that

> There is little research in the United States aimed at developing improved tools and methods for use in the early stages of the design of new naval ships. … Decisions made at the early design stages determine the basic architecture of the ship and ship systems and costs of construction and ownership [see also Keane, 2011]. … [T]here are basic research opportunities associated with generic technologies such as systems engineering, multidisciplinary optimization, set-based design, efficiency and accuracy of solvers, physics-based modeling, and multiphysics coupling techniques. These opportunities are particularly relevant for advanced ship concepts where there is often a lack of existing rules-based methods and experimental data and existing tools have not been verified, validated, or accredited for use. ... In summary, the health of basic and early applied research relevant to naval ship design tools can only be considered as poor in the United States.

These two studies recognized the need for "Cultural changes in the approach to requirements, ship design, and ship construction," which are also discussed in more detail by Sullivan (2011).

As Neches (2012) has argued elsewhere, current sequential processes effectively ensure that the right people are not available at the right time for optimal decision-making. There are, however, cost implications if additional stakeholders are simply asked to stand by or are tasked to review a greater number of decisions. Furthermore, the volume of information and proliferation of alternatives is too great to assume that simply making information available will ensure that it is noticed and acted upon. Accordingly, better tools and processes are needed in order to ensure that affordable, rapid, co-evolution of systems and missions can infuse designs, such that simple upgrades, refinements, and adaptations can take place throughout a system's lifecycle.

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Engineered Resilient Systems

From Today's Tools and Practices to Tomorrow's Investments: New Directions in Systems Engineering

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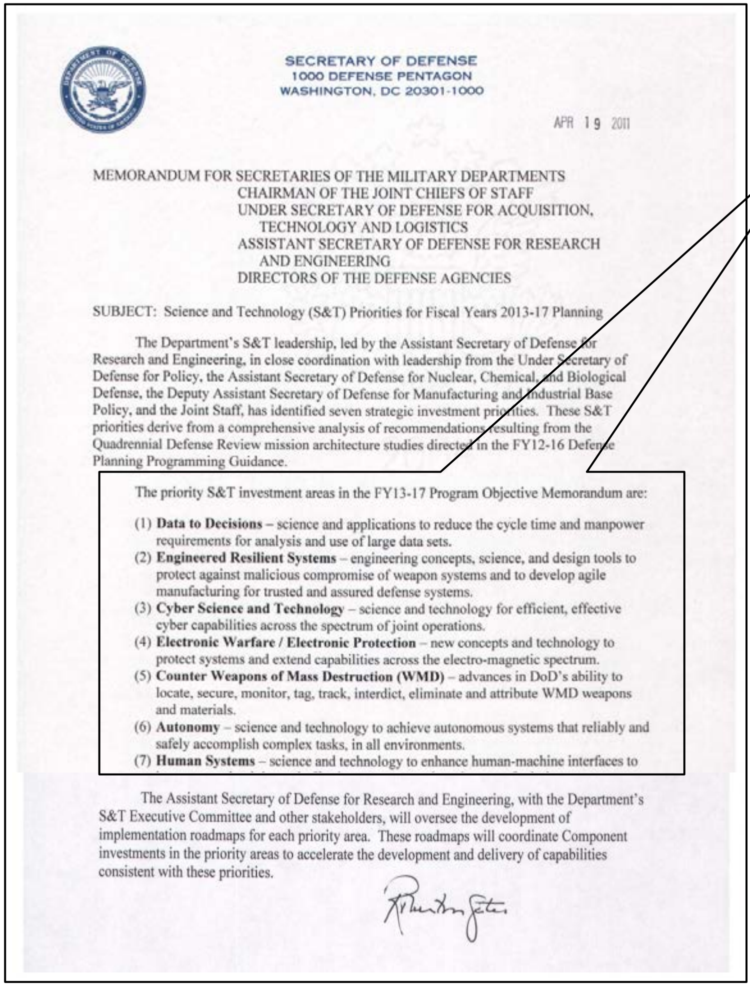
Secretary of Defense Guidance on Science & Technology (S&T) Priorities FY13-17



SECRETARY OF DEFENSE
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WASHINGTON, DC 20301-1000

APR 19 2011

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning

The Department's S&T leadership, led by the Assistant Secretary of Defense for Research and Engineering, in close coordination with leadership from the Under Secretary of Defense for Policy, the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense, the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy, and the Joint Staff, has identified seven strategic investment priorities. These S&T priorities derive from a comprehensive analysis of recommendations resulting from the Quadrennial Defense Review mission architecture studies directed in the FY12-16 Defense Planning Programming Guidance.

The priority S&T investment areas in the FY13-17 Program Objective Memorandum are:

(1) **Data to Decisions** – science and applications to reduce the cycle time and manpower requirements for analysis and use of large data sets.
(2) **Engineered Resilient Systems** – engineering concepts, science, and design tools to protect against malicious compromise of weapon systems and to develop agile manufacturing for trusted and assured defense systems.
(3) **Cyber Science and Technology** – science and technology for efficient, effective cyber capabilities across the spectrum of joint operations.
(4) **Electronic Warfare / Electronic Protection** – new concepts and technology to protect systems and extend capabilities across the electro-magnetic spectrum.
(5) **Counter Weapons of Mass Destruction (WMD)** – advances in DoD's ability to locate, secure, monitor, tag, track, interdict, eliminate and attribute WMD weapons and materials.
(6) **Autonomy** – science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments.
(7) **Human Systems** – science and technology to enhance human-machine interfaces to

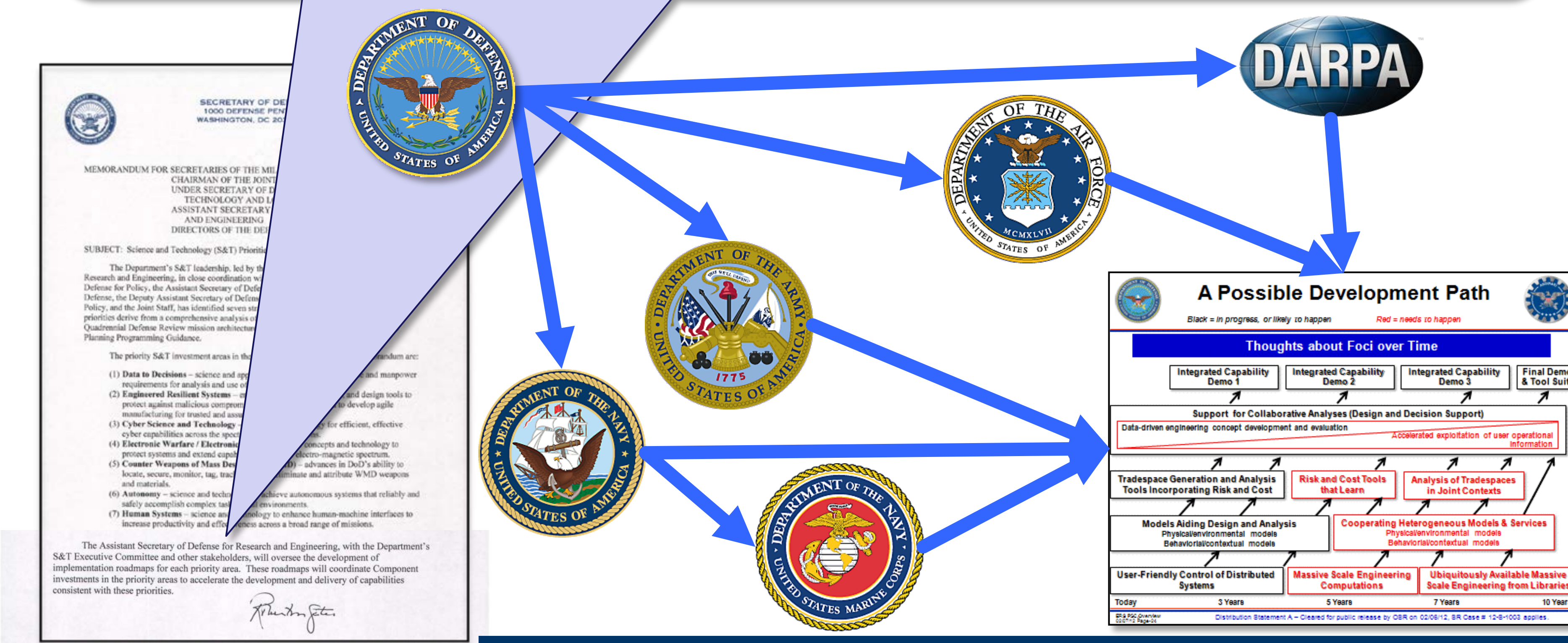
The Assistant Secretary of Defense for Research and Engineering, with the Department's S&T Executive Committee and other stakeholders, will oversee the development of implementation roadmaps for each priority area. These roadmaps will coordinate Component investments in the priority areas to accelerate the development and delivery of capabilities consistent with these priorities.

Priority S&T Investment Areas:

1. Data to Decisions
2. Engineered Resilient Systems
3. Cyber Science and Technology
4. Electronic Warfare / Electronic Protection
5. Counter Weapons of Mass Destruction
6. Autonomy
7. Human Systems

Engineered Resilient Systems: A DoD-wide Activity

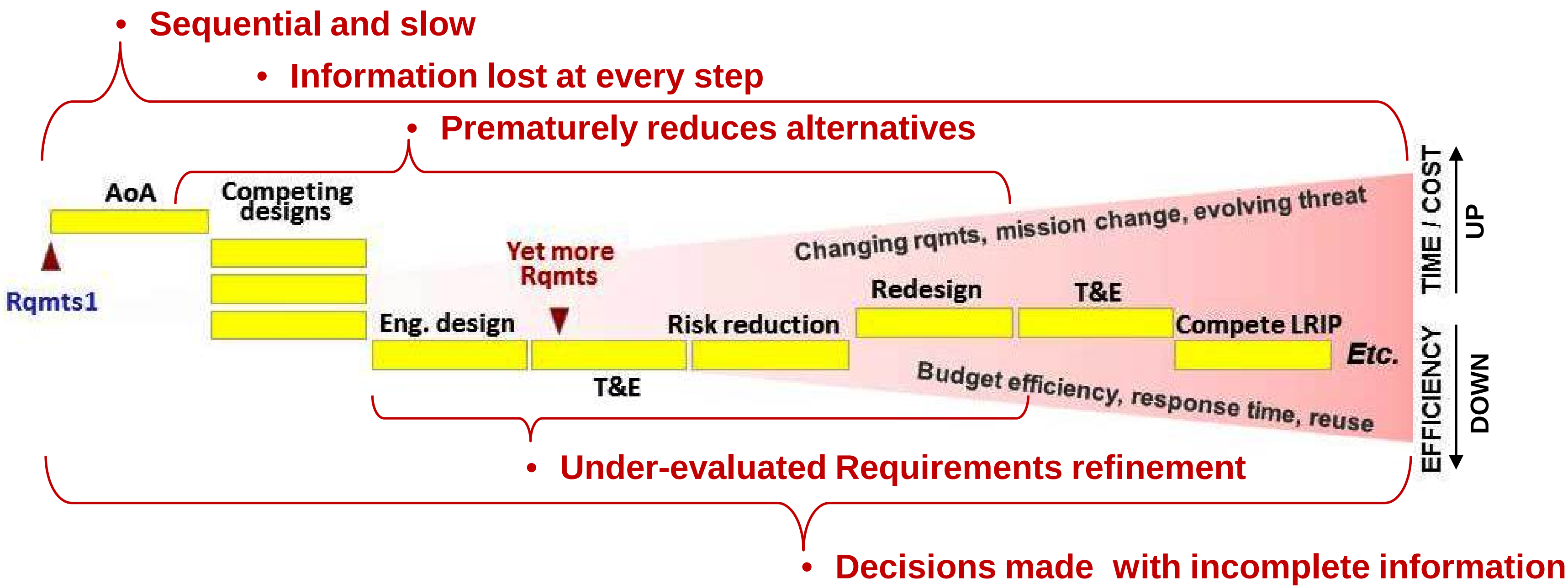
The Assistant Secretary of Defense for Research and Engineering, with the Department's S&T Executive Committee and other stakeholders, will oversee the development of implementation roadmaps for each priority area. These roadmaps will coordinate Component investments in the priority areas...



Working Toward A DoD-Wide Roadmap

Conventional Engineering Practice

50 years of process reforms haven't controlled time, cost and performance



Engineering practice must meet new challenges:

- **Pace of technology development**
- **Uncertain sociopolitical futures**
- **Global availability of technology to potential competitors**

Transforming Engineering of Complex Systems

Engineering for resilience: *robust* systems with *broad utility*

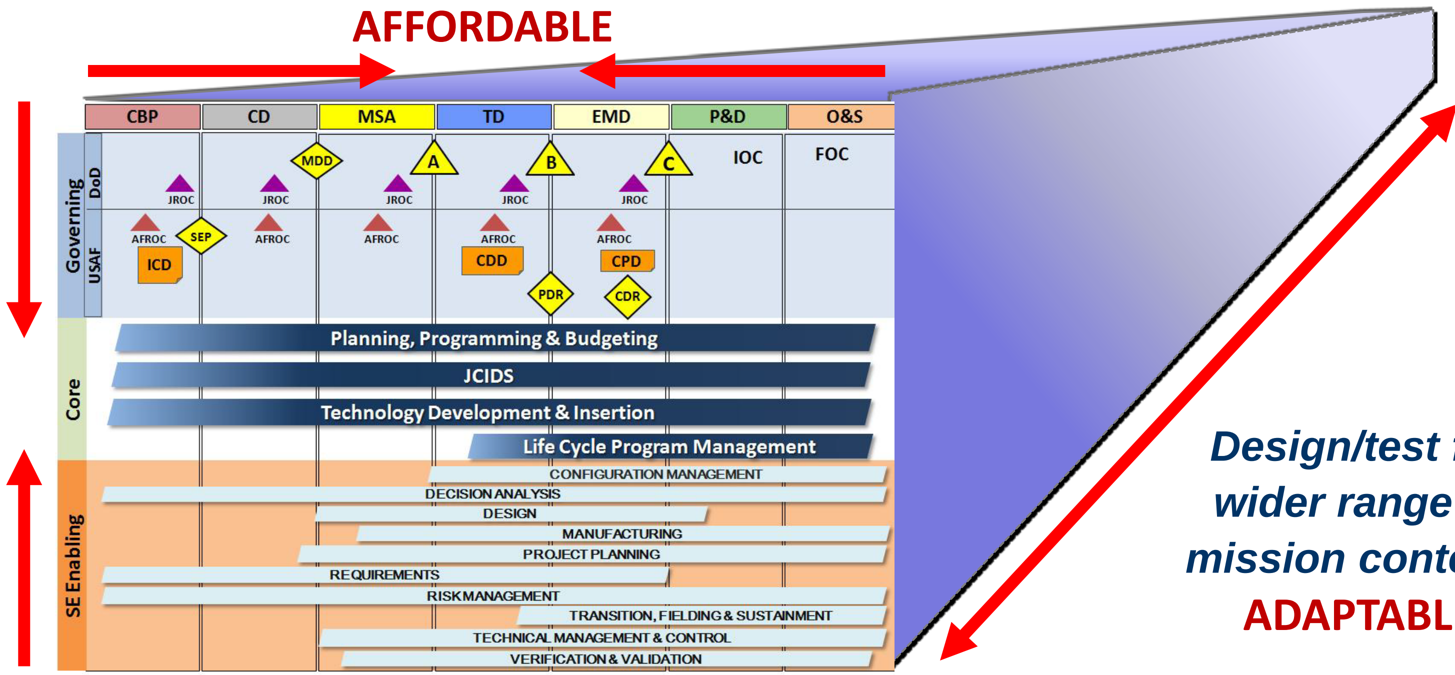
- ***In a wide range of joint operations***
- ***Across many potential alternative futures***

Faster engineering, less rework

AFFORDABLE

Better informed decision-making

EFFECTIVE



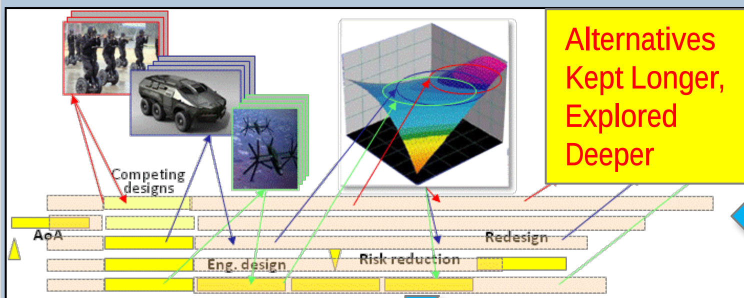
Design/test for wider range of mission contexts

ADAPTABLE

Engineered Resilient Systems

Transformational Engineering Practices

Increased computational power and availability allow more flexibility in data exploitation and application of services



New tools help engineers & users:

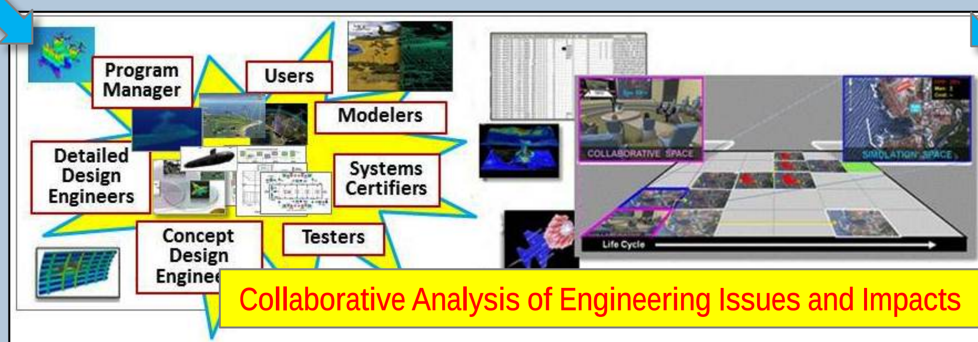
- ***Understand interactions***
- ***Identify implications***
- ***Manage consequences***

Effective

- ***Better informed***

Affordable

- ***Faster engineering***



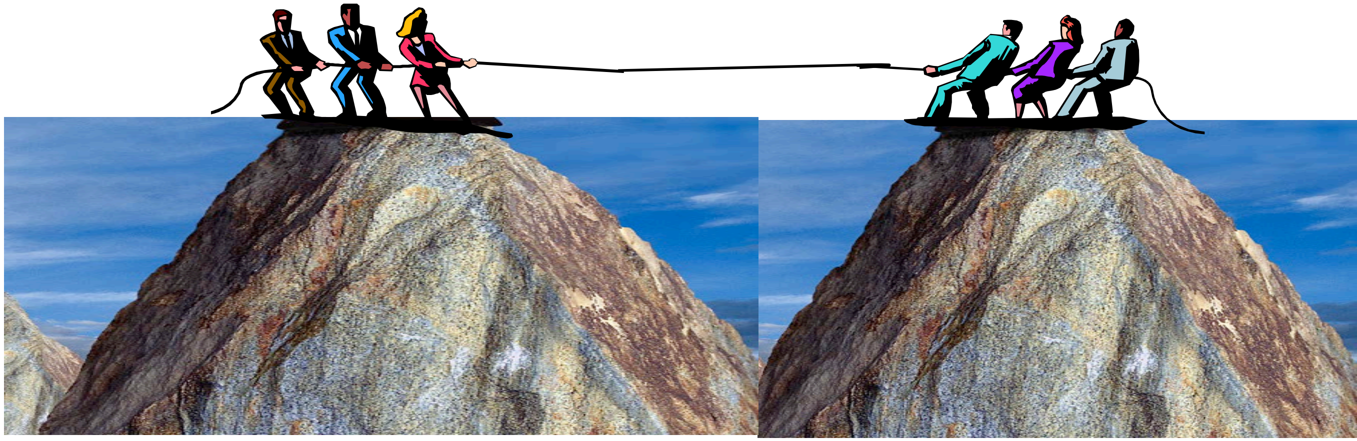
Adaptable

- ***Wider range of mission contexts***

ERS envisions an ecosystem in which a wide range of stakeholders continually cross-feed multiple types of data that inform each other's activities

Who Owns the Tools?

No Single Winning Answer



Pull too hard and everyone loses

Looking for a Win-Win

- **Tools for Government**
  - **Better understanding and specifier of needs**
  - **Better evaluator of offerings**
- **Tools for Systems Providers**
  - **Risk mitigation through better understanding of customer**
  - **Ability to pre-qualify offerings, present meaningful opportunities**
- **Tool Vendors: New Products to Sell Both**

Key Connectors are Data Exchange Protocols and Architectures

Envisioned End State

Improved Engineering and Design Capabilities

- More environmental and mission context
- More alternatives developed, evaluated and maintained
- Better trades: managing interactions, choices, consequences

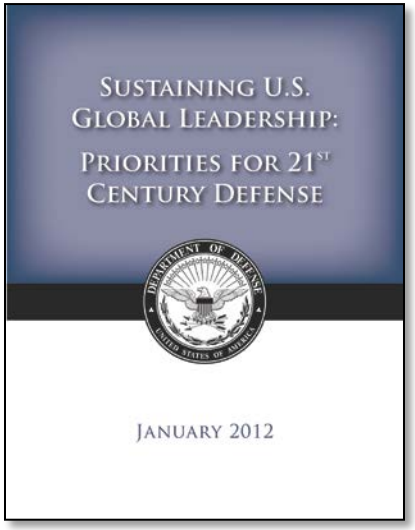
Improved Systems

- Highly effective: better performance, greater mission effectiveness
- Easier to adapt, reconfigure or replace
- Confidence in graceful degradation of function

Improved Engineering Processes

- Fewer rework cycles
- Faster cycle completion
- Better managed requirements shifts

ERS: Foundational for Defense Systems across All Mission Areas

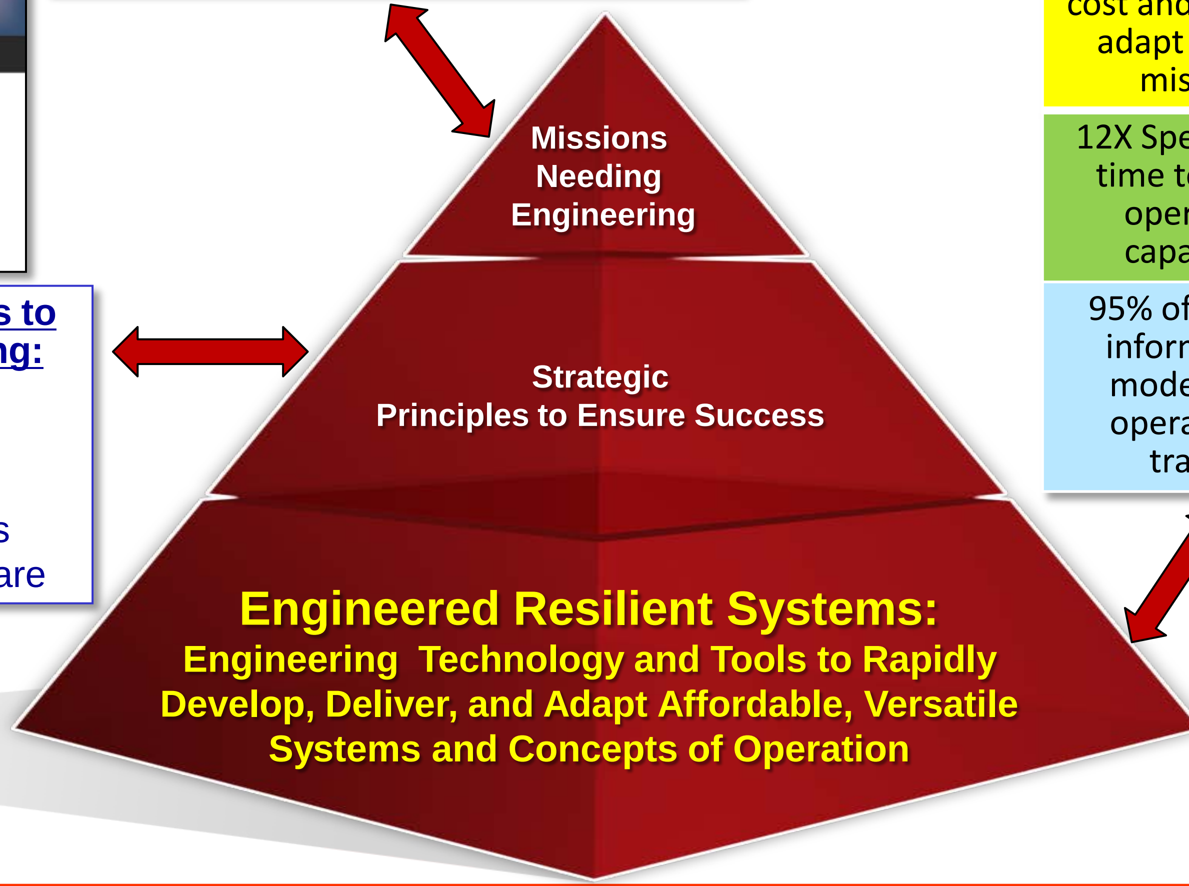


Ten DoD Strategic Missions

Overwhelming majority require affordable, adaptable & effective systems and Concepts of Operation:

Seven Strategic Principles to Ensure Success, including:

- Offer versatility
- Enable course changes
- Reduce costs
- Develop new capabilities leveraging network warfare



Target Outcomes

- 50% reduction in cost and effort to adapt to new mission
- 12X Speed up in time to initial operating capability
- 95% of system informed by models and operational trades